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# Impact of power ultrasound on the quality of fruits and vegetables during dehydration

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**Abstract**

In the present work, the influence of power ultrasound (US) on the quality of fruits and vegetables during both the pre-treatment and drying has been evaluated. Chemical indicators such as pectinmethyl esterase and peroxidase enzymes, vitamin C, carbohydrates, proteins, polyphenols and 2-furoylmethylamino acids (indicators of the early stages of Maillard reaction) have been studied. In addition, rehydration capacity, leaching losses and shrinkage and organoleptic characteristics of the final product have also been assessed. During blanching, similar leaching losses and enzyme inactivation were found in low temperature and prolonged conventional treatments and in US processes, but with a significant reduction in the time for the latter. Finally, application of US in drying of carrots and strawberries originated significant reductions in processing time, while providing high quality end-products. The quality was higher as compared to marketed products and superior or equivalent to samples obtained under similar conditions in a prototype convective dryer, and, in the case of some indicators, similar to that of freeze-dried samples.

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*Keywords:* high-intensity ultrasound; quality; carrot; strawberry; vitamin C; Maillard reaction

## 1. Introduction

The demands of consumers toward safe and nutritive foods with good organoleptic characteristics have promoted the constant evolution of technologies for the processing of food. The current interest in healthy food consumption


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has led to food industry toward challenges in the design of new products and ingredients with specific properties, paying special attention to those derived from fruits and vegetables. Since both, fruits and vegetables, have a very short shelf-life due to their elevate water content (greater than 80%) and, in most of the cases, their seasonal production, it is necessary to subject them to preservation processes, dehydration being one of the most feasible options.

Although dehydration has been known since long time ago, its use is expanding by the current lifestyle. Dried vegetables and fruits can be easily produced and stored and transported at relatively low cost. In addition, the resulting products have characteristics other than those of fresh products, expanding and diversifying the existing market. To date, most of dehydrated vegetables and fruits are obtained by convective drying, normally preceded by blanching treatment or osmotic dehydration. Although products with a long shelf-life are obtained by this method, their quality, in most of the cases, is quite far from that required by today's consumer, due to the physical and chemical changes that are originated.

To ensure that the constituents of foods exert a beneficial health effect, it is necessary the evaluation and authentication of the benefit of the compound and the knowledge of the changes that can take place during the processing of food and its subsequent storage. In this sense, it is important to apply processes that maintain nutritional and organoleptic properties and bioactivity. Thus, as it has been demonstrated, the optimization of existing technologies and the introduction of other emerging ones, can lead to a significant reduction in times and temperatures of processing, which is of great importance to preserve thermolabile constituents, such is the case of those present in fruits and vegetables (García-Pérez et al., 2012a; Barati and Esfahani, 2013). In addition, other very important aspect to consider is the use of more efficient, sustainable and eco-friendly processes as compared to their conventional counterparts. Thus, ultrasound (US) are a clear example of new technology with a lot of applications in the food processing. Recent works (Soria and Villamiel, 2010; Chemat et al., 2011; Cárcel et al., 2012; Pringet et al., 2013; Moses et al. 2014; Tao and Sun, 2015) have pointed out the great potential of the US in the field of Food Science and Technology, being the dehydration of fruits and vegetables one of the most promising applications.

This work has the purpose of showing a summary of the investigations carried out in our research group (Gamboa-Santos, 2013) on the study of the impact of power US during the dehydration process of vegetables and fruits, with particular attention to the chemical and physical changes that can take place; all of this aimed to the obtainment of high quality foods that satisfy the nutritional needs of consumers, their preferences and maintain the bioactivity of the raw fruits and vegetables.

## 2. Development of the work and main results obtained

As raw materials, carrots and strawberries were selected because of their high consumption and healthy and nutritious properties due to high content in bioactive constituents. In order to evaluate the quality and bioactivity of these dehydrated products, different quality indicators were selected: polyphenol oxidase (POD), pectinmethylesterase (PME), vitamins, compounds of the initial stages of Maillard reaction (MR) (2-furoylmethyl amino acids, 2-FM-AA), polyphenols, carbohydrates, proteins, rehydration, microstructure and sensory properties.

### *2.1. Pre-treatments of carrot assisted by US*

Since not only the step of drying affects the final quality of dehydrated fruits and vegetables, it was necessary to know the influence of pre-treatments such as blanching. In general, this procedure is carried out to inactivate enzymes that could cause a significant deterioration of the product throughout the storage period. Therefore, in the first stage of the work, a study on the effectiveness of different pre-treatments, conventional and with US, on the inactivation of the POD and the PME and losses by leaching during blanching of carrot was done. Hardly any enzyme inactivation was observed in bath of US and in the assays with probe at low temperatures. However, with US probe and generation of heat, the highest values of enzyme inactivation (90 and 50% for POD and PME, respectively) were achieved with a treatment of 15 min and temperature up to 70 °C. As an example, Figure 1 depicts the inactivation of POD. The results obtained showed the combined effect of the US and the temperature and stressed the difficulty of identifying the mechanisms of enzyme inactivation by US, since cavitation can involve various mechanical and chemical effects. In addition, there are numerous extrinsic and intrinsic factors that can affect the process resulting in enzyme activation or inactivation (Cruz et al., 2006).

From the results obtained in this study, we could infer that US are particularly suitable as an alternative to conventional treatments LTLT (low temperature long time), which could originate products with lower textural modifications. Thus, attending enzymatic inactivation and losses by leaching, similar results were obtained for LTLT treatments at 60 °C for 40 minutes and with US probe for 10 minutes at temperatures up to 60 °C. In the latter, the use of the probe resulted in a reduction of 75% in pre-treatment time, which could represent significant energy savings. However, taking into account the enzymatic inactivation, among all the pre-treatment tested, the most effective were the corresponding to steam and boiling water during short time (HTST), which are the most often used in the industry.

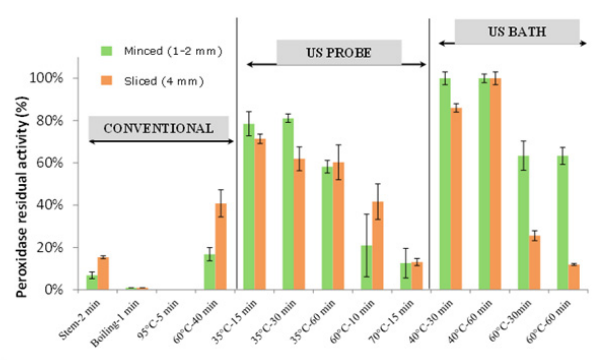


**Figure 1**. POD residual activity in minced and sliced carrot samples after different conventional and US blanching treatments.

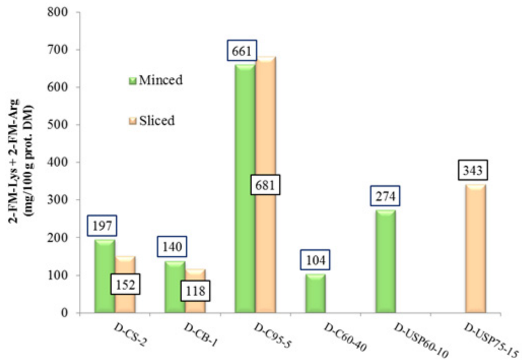


**Figure 2**. 2-FM-AA determination in dehydrated carrot samples previously subjected to different blanching pre-treatments.

## *2.2. Convective dehydration of carrot pre-treated by US*

Among all the assayed pre-treatments, we selected those with the highest enzyme inactivation and lower leaching losses. Subsequently, blanched carrots were dehydrated in a convective prototype of drying at optimal conditions previously established (46 ° C and 4.9 m/s), evaluating the effects of the pre-treatment in the final quality of the dried products. It was observed that blanching conditions particularly affect the formation of the 2-FM-AA during of drying, probably due to changes in the structure of the protein during the pre-treatment. In particular, dehydrated carrot samples subjected to prior treatment with US had relatively high levels of 2-FM-AA, despite the low temperatures and short time employed in the pre-treatments (Figure 2). Therefore, the mechanical effects provoked by US might be the main cause of such structural changes. Thus, it has been found that, US can facilitate the exposition of hydrophilic areas of amino acids, favoring their interaction with reducing carbohydrates during the early stages of the MR (Mu et al., 2010).

Other important aspects of quality to consider in dehydrated products are their organoleptic characteristics. To carry out the sensory evaluation of these products the carrots are rehydrated, because the consumption of dehydrated vegetable products is usually after a process of rehydration in a liquid medium. Thus, in dried carrot samples analyzed previously, an assessment of their sensory quality was done by semi-trained panelists and we found that samples of carrots pre-treated with US presented adequate organoleptic properties and similar to that of samples obtained by conventional methods. As a complementary study, a differentiation of dehydrated carrots, on the basis of the pre-treatment applied to samples, was carried out studying mass spectral fingerprints obtained after the analysis using Head-Space ChemSensor System (electronic nose). Thus, samples of carrots that had not been distinguished by the panelists were classified in different groups using this methodology, stating the usefulness of this procedure in the differentiation of carrots processed under similar conditions or with similar composition.

*2.3. Application of US to the convective drying of carrots and strawberries*

Once studied the pre-treatments and their effect on the convective drying, in the following stage of this work we applied US for dehydrating carrot and strawberry as a possible alternative or complement to convection processes. In the search for efficient dehydration processes, several articles had already highlighted the promising results of the application of US power (Chemat et al., 2011; Cárcel et al., 2012; Kowalski and Pawlowski, 2015) mainly, due to its ability to accelerate the process of moisture loss. However, no research had been carried out on the quality and bioactivity of the final products, so far. Therefore, firstly, assays of carrot drying were conducted in a prototype of power US by contact and the overall quality of the final product was studied. In general, a scarce advance of the MR was observed (Table 1), corresponding to a minimal change in the protein profile, and, on the basis of the studied indicators (polyphenols, carbohydrates, rehydration ability), the quality of carrots treated with US was similar to that of carrots freeze-dried in the laboratory.

Finally, strawberry samples were processed in a convective drying assisted by power US without contact, studying, in addition to the quality, the kinetic of moisture loss through a diffusional model taking into account the external resistance to the mass transfer and shrinkage (Figure 3**)**. The effective diffusivity and the coefficient of mass transfer (k) were identified and these parameters increased for the implementation with US, which indicated the acceleration of the process, in a similar way to that previously found in the literature for other substrates (Ortuño et al., 2010; Cárcel et al., 2011; Ozuna et al.., 2011). In strawberry dehydrated samples, the loss of vitamin C, the formation of 2-FM-AA and rehydration properties were also determined. The implementation of power US not only reduced the time for drying between 13 and 44% but also maintained a high quality of the final product, according to the physical and chemical parameters studied. It is noteworthy that, even in the more severe conditions (70 °C, 60 W), strawberry samples showed elevated values of retention of vitamin C (> 65%) and scarce advance of MR. It was also found the microbiological safety of the product over a period of 6 months at room temperature storage. In addition, the evolution of vitamin C during that period was studied and similar losses in vitamin C (close to 50%) in samples dehydrated with and without US at the end of the storage period were found.

**Table 1.** 2-FM-AA concentration in dehydrated carrot by US an in commercial samples.

| CARROT SAMPLE | 2-FM-AA (mg/100 g protein) | | |
|---|---|---|---|
| | 2-FM-Lys + 2-FM-Arg | 2-FM-GABA | 2-FM-Ala |
| Freeze Dried (FD) | n.d. | n.d. | n.d. |
| FD blanched[1] | n.d. | n.d. | n.d. |
| US-60ºC | 23 ± 1 | tr | n.d. |
| US-60ºC blanched | 39 ± 1 | tr | n.d. |
| COMM1 | 848 ± 49 | 312 ± 10 | 98 ± 6 |
| COMM2 | 447 ± 11 | 279 ± 16 | 216 ± 34 |
| COMM3 | 426 ± 18 | 228 ± 19 | 119 ± 10 |
| COMM4 | 819 ± 102 | 599 ± 65 | 618 ± 82 |
| COMM5 | 416 ± 18 | 312 ± 6 | 154 ± 3 |
| COMM6 | 358 ± 14 | 152 ± 6 | 134 ± 1 |

[1]Blanching: 1 min boiling water

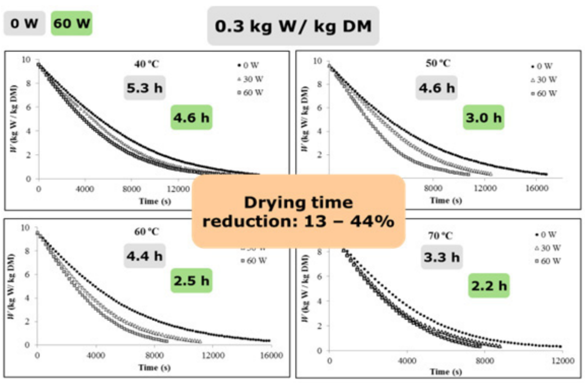


**Figure 3**. Drying kinetics of strawberry slabs (2 m/s, 40-70 °C) at different ultrasonic powers.

## Conclusions and future trends

According to the results found, in general, it can be considered, that samples of carrot and strawberry dehydrated under the effect of the US showed a higher quality than the commercial samples. Depending on the indicators used, the quality was equivalent to the samples dried by convection in similar conditions and even, in some aspects, to freeze-dried samples. The results found in this work intend to provide broad and innovative information on dehydration of fruits and vegetables to contribute to the obtainment of premium, safe and healthy foods and, thus, satisfy the needs of today's consumer. In this multidisciplinary work, different processes have been used such as convective and US assisted convective treatments with and without contact, and moreover, the effect of a previous blanching by US has been studied, showing the similarity of LTLT conventional processes and US treatment with probe during 10 min and temperature up to 60 °C. In addition, the application of different analytical technologies has allowed the determination of important physico-chemical and chemical quality parameters. However, despite the promising results, it is necessary to continue in the future in this line in order to establish the US as a technology of choice in the dehydration of foods in the industry. Current research in the field of sonochemistry is generally aimed at the improvement and design of ultrasonic systems (generators, reactors, transducers) in order to scale this technology and adapt to the processes required by food industries (Gallego-Juárez et al., 2010). It should be noted that the development of reactors of cavitation for treatment in continuous flow has contributed to introduce the application of US in liquid media on a large scale. Currently, in the industry, US are applied to homogenization, emulsification and extraction processes (Soria and Villamiel, 2010). On the contrary, regarding application of US in solid media, more research is needed on the optimization of processes, in order to develop more efficient treatments and obtain products of the highest quality. On the other hand, there are still many studies to be done revealing the exact mechanisms related to the effect of US on the plant tissue during dehydration. Nowadays, it is known that the most porous materials are more likely to suffer the "sponge effect" caused by the US (García-Pérez et al., 2012a; Rodriguez et al. 2014) and the obtainment of high quality products is mainly due to the acceleration of the drying process. The most recent studies are focused to avoid the heating during dehydration process to minimize the losses of thermolabile compounds. That is the case of the application of US during freeze-drying (García-Pérez et al., 2012b; Santacatalina et al. 2015). Other studies related to the optimization process would allow reaching conditions preserving nutritional or bioactives compounds. In parallel, studies on energy efficiency and evaluation of the process (pre-treatment and dehydration) costs would attract investment in the food industry towards the implementation of these emerging technologies to industrial dehydration processes.

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